Trends in Power Transmission and Motion Control

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1. INTRODUCTION

From about 1960 onwards there was a growing realisation that individual companies in the burgeoning fluid power industry could not act completely independently. There was an industry need for common standards, suitably trained engineers, fundamental research and interchange of ideas. And thus trade organisations and research groups began to be formed throughout the world. The JFPS was one of these.

Over the past 40 years the JFPS has established itself as one of the major organisations in the global fluid power scene. Through its Transactions and International Symposium it has played a particularly significant role in the dissemination of fluid power research. The Centre for Power Transmission and Motion Control (PTMC) at Bath, which is of a similar age, has had many valuable interactions with the JFPS over the years.

2. RESEARCH INSTITUTION

The University of Bath was founded in 1966. It has established an excellent reputation for teaching and research, with particular strengths in Science and Engineering. There are about 13 500 students taking first and higher degrees at the University.

The Centre for PTMC was founded in 1968. It is internationally recognised as a centre of excellence in fluid power, motion control, and engineering systems. Within these fields, the Centre's objectives are to stimulate high quality industrially-relevant research and teaching, and to provide short courses and consultancy services to industry. The Centre is staffed by a Director, 8 academics, 3 support staff, and 25 researchers.

3. SOME CURRENT RESEARCH ACTIVITIES

3.1 Fluid-borne noise

The Centre is well known for its fluid-born noise research, which has led to the development of International Standards for the measurement of flow ripple. A methodology has been developed to measure the impedance characteristics of a wide range of fluid power components. This allows prediction of pressure ripple within a circuit; the technique has been incorporated into a commercially available MATLAB/Simulink® toolbox called *Prasp*.(see Fig. 1).

Current areas of investigation include active cancellation techniques for fluid-borne noise (Fig. 2)[1], and pump condition monitoring using fluid-borne noise measurements [2].

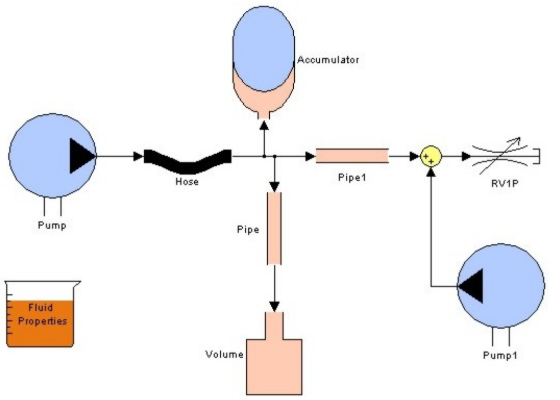

Fig. 1 Modelling fluid-borne noise using *Prasp*

3.2 Actuation

Component research is focussed on new actuation methods to improve performance and potentially reduce costs. One option is to make use of the complementary qualities of hydraulics and piezoelectric actuation. Fig. 3 shows a prototype Hörbiger valve actuated by a piezoelectric stack; in this arrangement the relatively small displacement of the stack is converted to large changes in flow [3].

The behaviour of dynamic seals remains of critical importance in fluid power. Another research study is investigating active seals, in which the properties of the seal can be actively controlled to match the current motion requirements (such as low or high speed).

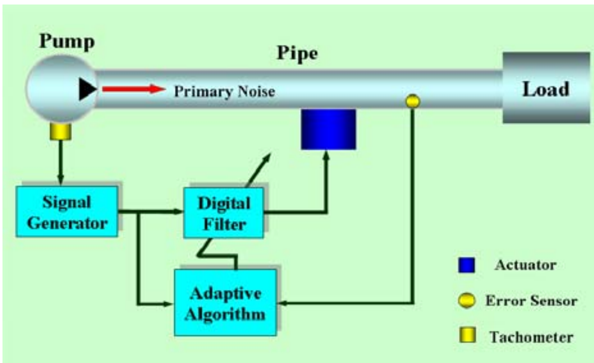

Fig. 2 Active control of fluid-borne noise

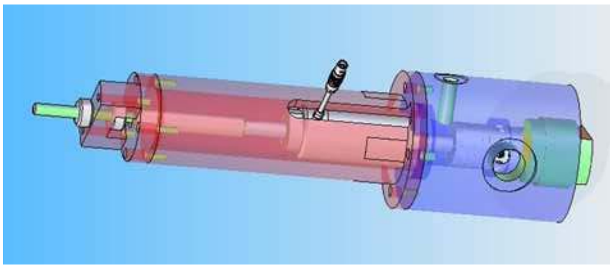

Fig. 3　Piezo-actuated Hörbiger valve

Two other ongoing projects are studying novel actuation for future aerospace applications, including high-power piezopumps, and low cost servovalves for use in civil aviation from 2020.

3.3　Systems, Control and Simulation

Predicting performance through modelling and computer simulation remains a technique which underpins all research projects. The development of more effective simulation approaches and processes is also a research goal in its own right.

The Centre's in-house fluid-circuit simulation tool, *Bathfp*, has also been developed for systems simulation including mechanical, electrical and control elements. *Bathfp* formed the basis of the successful commercial package, *AMESim*. The Centre's work on prediction of fluid-borne noise has already been discussed.

Research into controller design methods for electrohydraulic motion control systems is another active area. Recent work has included adaptive and robust control based on 'black-box' models, but also model-based control where non-linear physical models of the plant are included in the controller. Applications have included complex multi-axis systems such as shaking tables for earthquake simulation [4].

3.4　Applications

With increasing demand for close integration of engineering systems, more research now concerns optimising machine systems which incorporate fluid power just as one part. The development of the chassis, actuation and control systems for the narrow-track hydraulic-tilting vehicle CLEVER is one example (see Fig. 4).

Fig. 4　CLEVER hydraulic tilting vehicle.

Another example is power take off optimisation for wave energy converters, where the design and control of the hydraulic transmission system requires an intimate knowledge of the hydrodynamic response of the device[5].

Cross-fertilisation of research findings both from and to the fluid power field can also be fruitful. The Centre has applied many of the techniques developed for fluid power to other fluid systems, such as air-frame and aeroengine fuel systems. Fig. 5 shows validated CFD results for an aircraft fuel valve, for example.

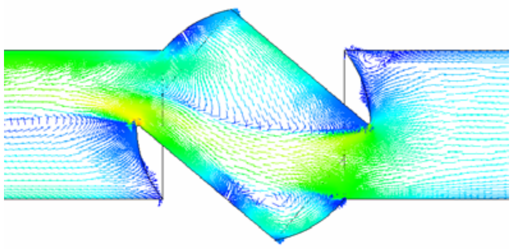

Fig. 5　CFD results for aircraft fuel system ball valve

4.THE FUTURE OF FLUID POWER

The transmission of power via the flow of fluid at high pressure will remain a key technology for the foreseeable future. It is more versatile and controllable than mechanical power transmission, and its power conversion components still have far superior power density compared to their electrical counterparts. However, the trend to integrate elements to make more effective machines will continue. Thus machines with closely-coupled fluid, mechanical, electrical, electronic, control and software elements, will become increasingly common, with each technology chosen to perform the function for which it is most suited.

The speed of evolution towards better integration is dependent on the availability of multi-disciplinary engineers, and the further development of computer-based analysis and synthesis tools. Currently the validity of computer simulation results is hard to assess before measured data is available, and specialised tools do not integrate well. However, for example, transient CFD (computational fluid dynamics) simulations running within systems models will soon become commonplace. The shift from tools which support analysis to those which explicitly help synthesis require multiple simulations to be run very quickly.

A particular challenge for fluid power systems is energy efficiency. Traditional valve-controlled hydraulic actuation wastes too much power for many new applications. Pump-controlled actuators, using either variable displacement or variable speed pumps, are one solution, but control response and fidelity may be compromised, and system weight and size increased. Another promising alternative for energy-efficient control is the digital switching valve concept [e.g. 6]. However all these approaches will lead to greater pressure ripple, and techniques (such as active noise control) will be required to mitigate this.

The new demand for energy-efficient machines also requires pumps and motors which have high efficiency over a wider operating range. Advances in tribology, including new materials and coatings, will play a part here. Retarding forces and torques generated by dissipative elements (brakes) are becoming less acceptable, energy needing to be stored instead and regenerated. Hydrostatic transmissions and accumulator storage provide some advantages over electrical alternatives in hybrid vehicles and renewable energy converters (wave and wind power).

The dynamic behaviour of a typical industrial digital controller still mimics that of its analogue forebear. Mostly, digital control has brought usability improvements, but limited improvement in closed loop control performance. Much of the academic work in controller design has proved insufficiently robust or too difficult to setup to be widely used. Thus the opportunity and challenge of exploiting the full power of digital control still remains. The most successful approaches to date have made use of a thorough understanding of the underlying physical system, rather than relying on 'black box' modelling alone. There is also scope for on-line condition monitoring, where actual and expected behaviour are compared to determine maintenance requirements

Active materials and fluids will also play a part in future systems. Piezo-actuated pumps and valves have already demonstrated useful performance traits – in fact fluid transmission is one of the most promising methods of harnessing the limited displacement, high frequency characteristics of piezoceramics. Controllable fluids – such as electro-rheological and magneto-rheological– provide alternative means for controlling fluid power systems, but draw backs of the fluids (such as life) still need to be overcome.

Small-scale (micro) fluid power systems will also emerge in the future, with applications in micro air vehicles, and micro-robotics. Development of low-friction sealing systems for high pressure micro-actuators and appropriate valve technology is required. 'Human-scale' hydraulics, with safety-oriented control systems is already emerging, such as in the first practical human exoskeleton designs.

Finally, fluid choices for an increasingly environmentally conscious world will change. Biodegradable fluids will become popular, and the pressure to further develop materials, components and systems capable of working reliably with water will intensify.

5. CONCLUSIONS

Over the next forty years the fluid power industry will change significantly. In traditional markets the pressure to reduce manufacturing costs will be a key driver. However there will also be many new markets, with alternative technologies competing to fulfill the power transmission and motion control needs of new machines. To achieve the best designs, the most appropriate technology has to be used, and fluid power will remain a competitive option as long as fundamental research continues to be supported, and engineers sufficiently knowledgeable in the field continue to be educated. Particularly through its International Symposia, JFPS will remain a major contributor in these areas.

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Andrew Plummer

Professor Plummer is the Director of the Centre for PTMC. He received his PhD degree from the University of Bath in 1991, for research in the field of adaptive control of electrohydraulic systems. He worked as a research engineer for Thales Training and Simulation developing motion and control loading system technology, before taking up a lecturing post at the University of Leeds, UK. From 1999 he was global control systems R&D manager for Instron, manufacturers of materials and structural testing systems. Here he developed a number novel model-based control methods for high performance electrohydraulic test systems, including crash-testing catapults, Formula One racing car test rigs, earthquake simulation tables, and high rate materials testing machines. Professor Plummer was appointed to his present position in 2006. He is Vice-Chair of the IMechE Mechatronics Informatics and Control Group, and sits on the editorial board for the IMechE Journal of Systems and Control Engineering.